6. COMBUSTION

This chapter presents estimates of the net GHG emissions from combustion of (1) each of the ten materials considered in this analysis, and (2) mixed MSW.

Combustion of municipal solid waste (MSW) results in emissions of CO_2 (because nearly all of the carbon in MSW is converted to CO_2), and N_2O, a potent greenhouse gas. Note, however, that CO_2 from burning biomass sources (such as paper products and yard trimmings) is not counted as a GHG, because it is biogenic (as explained in Section 1.6).

Combustion of MSW with energy recovery in a waste-to-energy (WTE) plant also results in <u>avoided</u> CO_2 emissions in two other industrial sectors. First, the electricity produced by a WTE plant displaces electricity that would otherwise be provided by an electric utility power plant. Because most utility power plants burn fossil fuels, and thus emit CO_2, the electricity produced by a WTE plant reduces utility CO_2 emissions. These avoided GHG emissions must be subtracted from the GHG emissions associated with combustion of MSW. Second, most MSW combusted with energy recovery in the US is combusted in WTEs that recover ferrous metals (e.g., steel).[59] The ferrous metals that are recovered are then recycled. Steel from recycled steel requires less energy than steel produced from iron ore, resulting in lower CO_2 emissions. Thus, the additional recycling of steel associated with MSW combustion reduces CO_2 emissions in steel manufacturing.

We analyzed the net GHG emissions from combustion of mixed MSW, and the following individual materials:

- newspaper,
- office paper,
- corrugated cardboard,
- aluminum cans,
- steel cans,
- HDPE plastic,
- LDPE plastic,
- PET plastic,
- yard trimmings, and
- food scraps.

Net emissions consist of (1) emissions of non-biogenic CO_2 and N_2O minus (2) avoided GHG emissions in the electric utility and steel sectors. There is some evidence that as combustor ash ages, it absorbs CO_2 from the atmosphere; however, we did not count CO_2 absorbed because we estimated the quantity absorbed to be

[59] We did not consider any recovery of materials from the MSW stream that may occur before MSW is delivered to the combustor. We considered such prior recovery to be unrelated to the combustion operation - unlike recovery of steel from combustor ash, an activity that is an integral part of the operation of many combustors.

less than 0.01 MTCE per ton of MSW combusted.[60] Combustion also results in emissions of nitrogen oxide (NO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) · all of which contribute indirectly to climate change.[61] However, we did not consider these gases in this analysis because there is no widely accepted method to estimate their contribution to climate change.[62]

Our results showed that combustion of mixed MSW has small positive net GHG emissions (in absolute terms). Combustion of paper products, food scraps, and yard trimmings results in negative net GHG emissions. Running steel cans through a combustor likewise results in negative net GHG emissions. Combustion of plastic produces large positive net GHG emissions, and combustion of aluminum cans results in small positive net GHG emissions. The reasons for each of these results are presented throughout this chapter.

6.1 METHODOLOGY

Our general approach was to estimate the (1) gross emissions of CO_2 and N_2O from MSW combustion (including emissions from transportation of waste to the combustor, and ash from the combustor to a landfill) and (2) CO_2 emissions avoided due to displaced electric utility generation and increased production of steel from recycled inputs.[63] To obtain an estimate of the net GHG emissions from MSW combustion, we subtracted the GHG emissions avoided from the direct GHG emissions. We estimated the net GHG emissions from waste combustion per ton of mixed MSW, and per ton of each selected material in MSW. The remainder of this section describes how we developed these estimates.

Estimating Direct CO_2 Emissions from MSW Combustion

The carbon in MSW has two distinct origins. Some of the carbon in MSW is biomass carbon (i.e., carbon in plant and animal matter that was converted from CO_2 in the atmosphere through photosynthesis). The remaining carbon in MSW is from non-biomass sources, e.g., plastic and synthetic rubber derived from petroleum.

We did not count the biogenic CO_2 emissions from combustion of biomass, as described in Section 1.6. On the other hand, we did count CO_2 emissions from combustion of non-biomass components of MSW

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[60] Based on data provided by Dr. Jurgen Vehlow [of Karlsruhe, Germany's Institut fur Technische Chemie], we estimated that the ash from one ton of MSW would absorb roughly 0.004 MTCE of CO_2.

[61] These gases contribute indirectly to climate change either because they are transformed in the atmosphere into a greenhouse gas or gases, or because they influence the atmospheric lifetimes of greenhouse gases.

[62] Because the Intergovernmental Panel on Climate Change (IPCC) has not established a method for estimating the global warming implications of emissions of these gases, we have not attempted such an estimation. Note, however, that NO and NO_2 emissions are believed to increase global warming, whereas SO_2 is believed to counteract global warming (by forming sulfate aerosols that reflect sunlight, and that aid in the formation of clouds, which also reflect sunlight).

[63] A comprehensive evaluation would also consider the fate of carbon remaining in combustor ash. Depending on its chemical form, carbon may be aerobically degraded to CO_2, anaerobically degraded to CH_4, or remain in a relatively inert form and be sequestered. Unless the ash carbon is converted to CH_4 (which we considered to be unlikely), the effect on the net GHG emissions would be very small.

plastic, textiles, and rubber. Overall, only a small portion of the total CO_2 emissions from combustion are counted as GHG emissions.

For mixed MSW, we used the simplifying assumptions that (1) all carbon in textiles was non-biomass carbon, i.e., petrochemical-based plastic fibers such as polyester (this is a worst-case assumption), and (2) the category of "rubber and leather" in EPA's MSW characterization report[64] was composed almost entirely of rubber. Based on these assumptions, we estimated that there are 0.11 pounds of non-biogenic carbon in the plastic, textiles, rubber, and leather contained in one pound of mixed MSW.[65] We assumed that 98 percent of this carbon would be converted to CO_2 when the waste was combusted, with the balance going to the ash. Then, we converted the 0.11 pounds of non-biomass carbon per pound of mixed MSW to units of metric tons of carbon equivalent (MTCE) per ton of mixed MSW combusted. The resulting value for mixed MSW is 0.10 MTCE per ton of mixed MSW combusted,[66] as shown in Exhibit 6-1.

We estimated that HDPE and LDPE are 84 percent carbon, while PET is 57 percent carbon.[67] (accounting for a moisture content of 2 percent). We again assumed that 98 percent of the carbon in the plastic is converted to CO_2 during combustion. The values for CO_2 emissions, converted to units of MTCE per ton of plastic combusted, are shown in column "b" of Exhibit 6-1.

Estimating N_2O Emissions from Combustion of Waste

Recent studies compiled by the Intergovernmental Panel on Climate Change (IPCC) show that MSW combustion results in measurable emissions of N_2O (nitrous oxide), a greenhouse gas with a high global warming potential (GWP).[68] The IPCC compiled reported ranges of N_2O emissions, per metric ton of waste combusted, from six classifications of MSW combustors. We averaged the midpoints of each range and converted the units to MTCE of N_2O per short ton of MSW; the resulting estimate is 0.01 MTCE of N_2O emissions per ton of mixed MSW combusted. Because the IPCC did not report N_2O values for combustion of individual components of MSW, we used the 0.01 value not only for mixed MSW, but also as a proxy for all components of MSW, except for aluminum and steel cans.[69]

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[64] U.S. EPA, Office of Solid Waste and Emergency Response, *Characterization of Municipal Solid Waste in the United States: 1994 Update*, November 1994.

[65] ICF Incorporated, "Work Assignment 239, Task 2: Carbon Sequestration in Landfills," memorandum to Michael Podolsky, Clare Lindsay, and Brett Van Akkeren of EPA, April 28, 1995, Exhibit 2-A, column "o."

[66] Note that if we had used a best-case assumption for textiles, i.e., assuming they had no petrochemical-based fibers, the resulting value for mixed MSW would have been 0.09 MTCE per ton of mixed MSW combusted.

[67] ICF Incorporated, *op cit*., Exhibit 1-A, column "n."

[68] Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual, Volume 3,* (undated) p. 6-33. The GWP of N_2O is 270 times that of CO_2.

[69] This exception was made because at the relatively low combustion temperatures found in MSW combustors, most of the nitrogen in N_2O emissions is derived from the waste, not from the combustion air. Because aluminum and steel cans do not contain nitrogen, we concluded that running these metals through an MSW combustor would not result in N_2O emissions.

Exhibit 6-1
Gross Emissions of Greenhouse Gases From MSW Combustion
(MTCE/Ton)

(a) Material Combusted	(b) Combustion CO_2 Emissions From Non-Biomass Per Ton Combusted	(c) Combustion N_2O Emissions Per Ton Combusted	(d) Transportation CO_2 Emissions Per Ton Combusted	(e) Gross GHG Emissions Per Ton Combusted
Newspaper	0.00	0.01	0.01	0.02
Office Paper	0.00	0.01	0.01	0.02
Corrugated Cardboard	0.00	0.01	0.01	0.02
Aluminum Cans	0.00	0.00	0.01	0.01
Steel Cans	0.00	0.00	0.01	0.01
HDPE	0.75	0.01	0.01	0.77
LDPE	0.75	0.01	0.01	0.77
PET	0.51	0.01	0.01	0.53
Food Scraps	0.00	0.01	0.01	0.02
Yard Trimmings	0.00	0.01	0.01	0.02
Mixed MSW	0.10	0.01	0.01	0.12

Estimating Indirect CO_2 Emissions from Transportation of Waste to the WTE Plant

Next, we estimated the indirect CO_2 emissions from the transportation of waste. For the indirect CO_2 emissions from transporting waste to the WTE plant, and ash from the WTE plant to a landfill, we used an estimate for mixed MSW developed by Franklin Associates, Ltd. (FAL).[70] We then converted the FAL estimate from pounds of CO_2 per ton of mixed MSW to MTCE per ton of mixed MSW. This resulted in an estimate of 0.01 MTCE of CO_2 emissions from transporting one ton of mixed MSW, and the resulting ash. We assumed that transportation of any individual material in MSW would use the same amount of energy as transportation of mixed MSW.

Estimating Gross Greenhouse Gas Emissions from Combustion

To estimate the gross GHG emissions per ton of waste combusted, we summed the values for emissions from combustion CO_2, combustion N_2O, and transportation CO_2. The gross GHG emissions estimates, for mixed MSW and for each individual material, are shown in column "e" of Exhibit 6-1.

Estimating Utility CO_2 Emissions Avoided

Most WTE plants in the US produce electricity. Only a few produce steam, and few if any cogenerate electricity and steam. Thus, in our analysis, we assumed that the energy recovered with MSW combustion would be in the form of electricity. Our analysis is shown in Exhibit 6-2. We used three data elements to estimate the avoided electric utility CO_2 emissions associated with combustion of waste in a

[70] Franklin Associates, Ltd., *The Role of Recycling in Integrated Solid Waste Management to the Year* 2000 (Stamford, CT: Keep America Beautiful, Inc.) September 1994, p. I-24.

Exhibit 6-2
Avoided Utility GHG Emissions from MSW Combustion

(a) Material Combusted	(b) Energy Content (BTUs per pound)		(c) Energy Content (1E6 BTUs per ton)	(d) Combustion System Efficiency (Percent)	(e) Emission Factor for Utility-Generated Electricity (MTCE/1E6 BTUs of electricity delivered)	(f) Avoided Utility CO_2 Per Ton Combusted (MTCE)
Newspaper	7,950	a	15.9	13.6%	0.05112	0.11
Office paper	6,800	a,b	13.6	13.6%	0.05112	0.09
Corrugated cardboard	7,043	a	14.1	13.6%	0.05112	0.10
Aluminum cans	-335	c	-0.7	13.6%	0.05112	0.00 *
Steel cans	-210	c	-0.4	13.6%	0.05112	0.00 *
HDPE	18,687	a	37.4	13.6%	0.05112	0.26
LDPE	18,687	a	37.4	13.6%	0.05112	0.26
PET	9,702	d,e	19.4	13.6%	0.05112	0.13
Yard trimmings	2,800	f	5.6	13.6%	0.05112	0.04
Food scraps	2,370	a	4.7	13.6%	0.05112	0.03
Mixed MSW	5,358	g	10.7	13.6%	0.05112	0.07

*The amount of energy absorbed by one ton of steel or aluminum cans in an MSW combustor would, if not absorbed, result in less than 0.01 MTCE of avoided utility CO2.

a MSW Fact Book.
b We used the MSW Fact Book's value for mixed paper as a proxy for the value for office paper.
c We developed these estimates based on data on the specific heat of aluminum and steel, and calculated the energy required to raise the temperature of aluminum or steel from ambient temperature to the temperature found in a combustor (about 750° Celsius). We obtained the specific heat data from Incropera, Frank P. and David P. DeWitt, Introduction to Heat Transfer, Second Edition (New York: John Wiley & Sons) 1990, pp. A3-A4.
d Gaines and Stodolsky.
e For PET plastic, we converted the value of 9,900 BTUs/pound dry weight, to 9,702 BTUs/pound wet weight, to account for a moisture content of 2 percent.
f Procter and Redfern, Ltd. and ORTECH International.
g Berenyi and Gould.

WTE plant: (1) the energy content of mixed MSW and of each separate waste material considered, (2) the combustion system efficiency in converting energy in MSW to delivered electricity, and (3) the electric utility CO_2 emissions avoided per kilowatt-hour of electricity delivered by WTE plants.

Energy content. For the energy content of mixed MSW, we used a value of 5,358 BTUs per pound of mixed MSW combusted, which was the mean value based on data from 133 (of the total of 171) municipal waste combustors in the US that provided data in a survey by Governmental Advisory Associates

(GAA).[71] This estimate is about the midpoint of the range of values (4,500 to 6,500 BTUs per pound) reported by FAL,[72] and is slightly higher than the 4,800 BTUs per pound value reported in EPA's MSW Fact Book.[73] For the energy content of specific materials in MSW, we evaluated three sources: (1) EPA's MSW Fact Book (a compilation of data from primary sources), (2) a report by the Canadian government,[74] and (3) a report by Argonne National Laboratories.[75] We assume that the energy contents reported in the first two of these sources were for materials with moisture contents typically found for the materials in MSW (the sources implied this, but did not explicitly state it). The Argonne study reported energy contents on a dry weight basis.

Combustion system efficiency. To estimate the combustion system efficiency of WTE plants, we began with GAA's reported net value of 471 kWh generated by WTE plants per ton of mixed MSW combusted.[76] This value is consistent with the net 480 kWh generated per ton of mixed MSW reported by FAL.[77] Next, we considered losses in transmission and distribution of electricity, and used the US average transmission and distribution loss of 9 percent,[78] to estimate that 429 kWh are delivered per ton of waste combusted.

We then used the value for the delivered kWhs per ton of waste combusted to derive the implicit combustion system efficiency (i.e., the percentage of energy in the waste that is ultimately delivered in the form of electricity). To determine this efficiency, we first estimated the BTUs of MSW needed to deliver one kWh of electricity. We divided the BTUs per ton of waste by the delivered kWh per ton of waste to obtain the BTUs of waste per delivered kWh. The result is 25,000 BTUs per kWh. Next we divided the physical constant for the energy in one kWh (3,412 BTUS) by the BTUs of MSW needed to deliver one kWh, to estimate the total system efficiency at 13.6 percent.[79] This relatively low efficiency of combustion

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[71] Berenyi, Eileen B. and Robert N. Gould, *Resource Recovery Yearbook 1993-94* (New York, NY: Governmental Advisory Associates, Inc.) 1993, p. 47.

[72] Franklin Associates, Ltd., p. 1-16.

[73] U.S. Environmental Protection Agency, Office of Solid Waste, *MSW Fact Book, Version 2.0* (Washington, D.C.: U.S. Environmental Protection Agency) April 1995.

[74] Procter and Redfern, Ltd. and ORTECH International, *Estimation of the Effects of Various Municipal Waste Management Strategies on Greenhouse Gas Emissions, Part II* (Ottawa, Canada: Environment Canada, Solid Waste Management Division, and Natural Resources Canada, Alternative Energy Division), September 1993.

[75] Gaines, Linda, and Frank Stodolsky, "Mandated Recycling Rates: Impacts on Energy Consumption and Municipal Solid Waste Volume" (Argonne, IL: Argonne National Laboratory) December 1993, pp. 11 and 85.

[76] Berenyi and Gould, op cit, p. 46.

[77] Franklin Associates, Ltd., op cit, p. 1-21.

[78] U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1993* (Washington, D.C.: Energy Information Administration) July 1994, p. 252.

[79] Note that the total system efficiency is the efficiency of translating the energy content of the fuel into the energy content of delivered electricity. The relatively low system efficiency of 13.6 percent reflects losses in (1) converting energy in the fuel into steam, (2) converting energy in steam into electricity, and (3) delivering

is due in part to the absorption of heat energy by moisture (as well as metals and glass) in MSW. We recognize that combustors dedicated to a single type of high-BTU waste, such as paper, may be able to achieve a higher combustion system efficiency, but we did not estimate the net GHG emissions from such combustors. Moreover, it is likely that new combustion capacity would have a higher efficiency than the average existing combustion facility.

Electric utility carbon emissions avoided. To estimate the avoided utility CO_2 from waste combustion, we used the results in columns "c" and “d,” together with a "carbon coefficient" of 0.051 MTCE emitted per million BTUs of utility-generated electricity (delivered), based on the national average fuel mix used by utilities.[80] This approach implicitly uses the average fuel mix as a proxy for the fuels displaced at the margin when utility-generated electricity is displaced by electricity from WTE plants. The actual carbon reductions could vary depending on which type of fuel used to generate electricity is displaced at the margin. The resulting estimates for utility carbon emissions avoided for each material are shown in column "f" of Exhibit 6-2.

Approach to Estimating CO_2 Emissions Avoided Due to Increased Steel Recycling

We next estimated the avoided CO_2 emissions from increased steel recycling made possible by steel recovery from WTE plants for (1) mixed MSW and (2) steel cans.

For mixed MSW, we estimated the amount of steel recovered per ton of mixed MSW combusted, based on (1) the amount of MSW combusted in the US, and (2) the amount of steel recovered, post-combustion. Ferrous metals are recovered at sixty-five MSW combustion facilities in the US. These facilities account for approximately 75 percent of the 32 million tons of MSW combusted per year, and recover a total of about 532,000 tons per year of ferrous metals.[81] By dividing 532,000 tons by 32 million tons, we estimated that 0.02 tons of steel are recovered per ton of MSW combusted (as a national average).

For steel cans, we first estimated the national average proportion of steel cans entering WTE plants that would be recovered. As noted above, approximately 75 percent of MSW destined for combustion goes to facilities with a ferrous recovery system; at these plants, approximately 98 percent of the steel cans would be recovered.[82] We multiplied these percentages to estimate the weight of steel cans recovered per ton of steel cans combusted · about 0.74 tons per ton.

Finally, to estimate the avoided CO_2 emissions due to increased recycling of steel, we multiplied (1) the weight of steel recovered by (2) the avoided CO_2 emissions per ton of steel recovered. Thus, we estimated avoided CO_2 emissions of 0.42 MTCE per ton for steel cans, and 0.01 MTCE per ton for MSW, as shown in column "d" of Exhibit 6-3.

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electricity. The losses in delivering electricity are the transmission and distribution losses, estimated at 9 percent.

[80] R. Neal Elliott, "Carbon Reduction Potential from Recycling in Primary Materials Manufacturing" (Washington, D.C.: American Council for an Energy-Efficient Economy) February 8, 1994, p. 14.

[81] Telephone conversation, David Sussman, Senior Vice President for Environmental Affairs, Ogden Corporation, with William Driscoll, ICF, April 4, 1995.

[82] Telephone conversation, David Sussman with William Driscoll, May 12, 1995.

Exhibit 6-3
Avoided GHG Emissions Due to
Increased Steel Recovery from MSW Combustors

(a) Material Combusted	(b) Tons of Steel Recovered Per Ton of Waste Combusted (tons)	(c) Avoided CO_2 Emissions Per Ton of Steel Recovered (MTCE/ton)	(d)* Avoided CO_2 Emissions Per Ton of Waste Combusted (MTCE/ton)
Newspaper	NA	NA	NA
Office paper	NA	NA	NA
Corrugated cardboard	NA	NA	NA
Aluminum cans	NA	NA	NA
Steel cans	0.735	0.57	0.42
HDPE	NA	NA	NA
LDPE	NA	NA	NA
PET	NA	NA	NA
Yard trimmings	NA	NA	NA
Food scraps	NA	NA	NA
Mixed MSW	0.017	0.57	0.01

*The value in column "d" is a national average, and is weighted to reflect 98 percent recovery at the 75 percent of facilities that recover ferrous metals.

6.2 RESULTS

The results of our analysis are shown in Exhibit 6-4. The results from the last columns of Exhibits 6-1, 6-2, and 6-3 are shown in columns "b," "c," and "d," respectively, of Exhibit 6-4. The net GHG emissions from combustion of each material are shown in column "e." These net values represent the gross GHG emissions (column "b"), minus the avoided GHG emissions (columns "c" and "d"). As stated earlier, these net GHG emissions estimates are absolute values, not values relative to some other waste management option.

We estimate that combustion of mixed MSW has slightly positive net GHG emissions of 0.04 MTCE per ton. Combustion of paper products has negative net GHG emissions of approximately -0.1 MTCE per ton, because CO_2 emissions from burning paper are not counted and fossil fuel burning by utilities is avoided. Combustion of food scraps and yard trimmings (two other forms of biomass) also has negative net GHG emissions, but of a smaller magnitude (-0.01 to -0.02 MTCE per ton of material).

Combustion of plastics results in substantial net GHG emissions estimated at 0.39 to 0.51 MTCE per ton. This is primarily because of the high content of non-biomass carbon in plastics. Also, when combustion of plastic results in electricity generation, the utility carbon emissions avoided (due to displaced utility fossil fuel combustion) are much less than the carbon emissions from the combustion of plastic. This is largely due to the lower system efficiency of WTE plants, compared to electric utility plants. Recovery of ferrous metals at combustors results in negative net GHG emissions, estimated at -0.41 MTCE per ton of steel cans, due to the increased steel recycling made possible by ferrous metal recovery at WTE plants. Combustion of aluminum cans, on the other hand, results in slight positive net GHG emissions of 0.01 MTCE per ton, due to the energy used in transporting the cans to the WTE plant.

Exhibit 6-4
Net GHG Emissions from MSW Combustion

(a) Material Combusted	(b) Gross GHG Emissions Per Ton Combusted (MTCE/ton)	(c) Avoided Utility CO_2 Per Ton Combusted (MTCE/ton)	(d) Avoided CO_2 Emissions Per Ton Combusted Due to Steel Recovery (MTCE/ton)	(e) Net GHG Emissions from Combustion (MTCE/ton)
Newspaper	0.02	0.11	NA	-0.09
Office paper	0.02	0.09	NA	-0.07
Corrugated cardboard	0.02	0.10	NA	-0.08
Aluminum cans	0.01	0.00	NA	0.01
Steel cans	0.01	0.00	0.42	-0.41
HDPE	0.77	0.26	NA	0.51
LDPE	0.77	0.26	NA	0.51
PET	0.53	0.13	NA	0.39
Yard trimmings	0.02	0.04	NA	-0.02
Food scraps	0.02	0.03	NA	-0.01
Mixed MSW	0.12	0.07	0.01	0.04

6.3 LIMITATIONS OF THE ANALYSIS

The reliability of the analysis presented in this chapter is limited by the reliability of the various data elements used. The most significant limitations are as follows:

- Combustion system efficiency of WTE plants may be improving. A survey of planned WTE plants shows an expected efficiency improvement of 14 percent over current plants.[83] If efficiency improves, more utility CO_2 will be displaced per ton of waste combusted (assuming no change in utility emissions per kWh), and the net GHG emissions from combustion of MSW will decrease.

- The reported ranges for N_2O emissions were broad; in some cases the high end of the range was 10 times the low end of the range. Research has indicated that N_2O emissions vary with the type of waste burned. Thus, the average value used for mixed MSW and for all MSW components should be interpreted as an approximate value.

- For mixed MSW, we assumed that all carbon in textiles is from synthetic fibers derived from petrochemicals (whereas, in fact, some textiles are made from cotton, wool, and other natural fibers). Because we assumed that all carbon in textiles is non-biogenic, we counted all of the CO_2 emissions from combustion of textiles as GHG emissions. This assumption will slightly overstate the net GHG emissions from combustion of mixed MSW, but the magnitude of the error is small because textiles represent only a small fraction of the MSW stream. Similarly, the MSW category of "rubber and leather" contains some biogenic

[83] Berenyi and Gould, op cit, p. 46.

carbon from the leather. By not considering this small amount of biogenic carbon, the analysis slightly overstates the GHG emissions from MSW combustion.

- Because the makeup of a given community's mixed MSW may vary from the national average, the energy content may also vary from the national average energy content that we used in this analysis. For example, MSW from communities with a higher or lower than average recycling rate may have a different energy content, and MSW with more than the average proportion of dry leaves and branches will have a higher energy content.

- In our analysis, we used the national average recovery rate for steel. Where waste is sent to a WTE plant *with* steel recovery, the net GHG emissions for steel cans will be slightly lower (i.e., more negative). Where waste is sent to a WTE plant *without* steel recovery, the net GHG emissions for steel cans will be the same as for aluminum cans (i.e., close to zero).

- We used in this analysis the national average fuel mix for electricity as the proxy for fuel displaced at the margin when WTE plants displace utility electricity. If some other fuel or mix of fuels is displaced at the margin (e.g. coal), the avoided utility CO_2 would be different (e.g., for coal, the avoided utility CO_2 would be about 0.025 MTCE per ton higher for mixed MSW, and the net GHG emissions would be 0.01 MTCE instead of 0.04 MTCE per ton).

- Combustors dedicated to a single type of high-BTU waste, such as paper, may be able to achieve a higher combustion system efficiency, but we did not estimate the net GHG emissions from such combustors.